Muon Collider Acceleration

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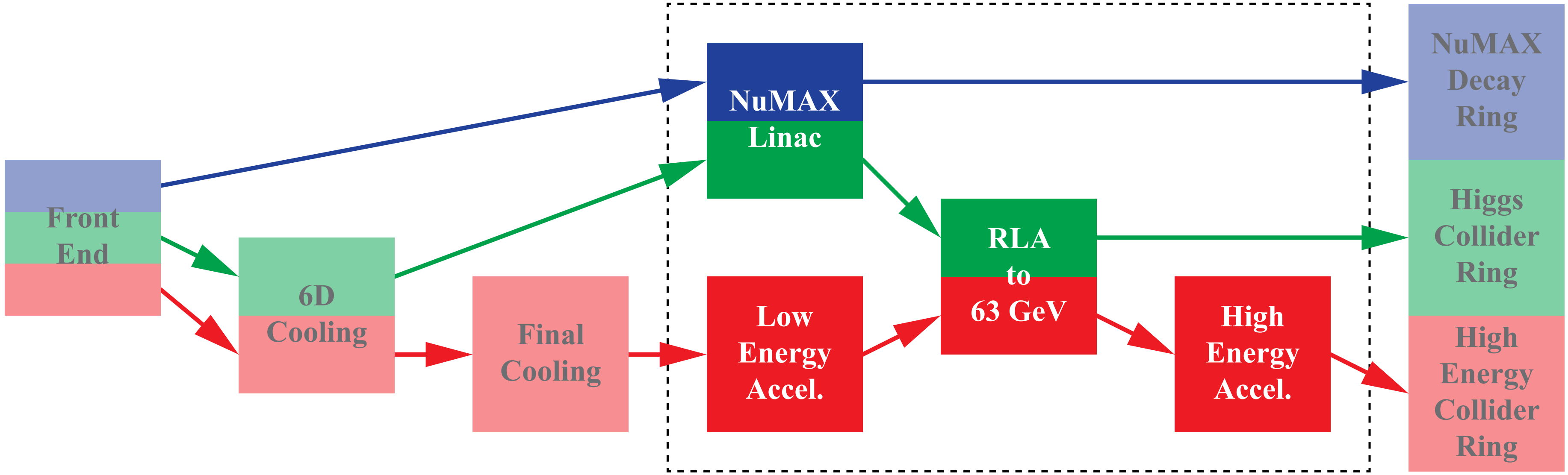
Outline

- High level view of acceleration (previous meeting)
- Dogbone RLA design considerations
- Pulsed synchrotrons

Muon Accelerators



Muon Acceleration

- Three classes of machines
  - NuMAX: neutrino factory to 5 GeV
  - Higgs factory: 63 GeV collider
  - High energy colliders: 1.5, 3, ≈6 TeV, and higher CoM
- Four acceleration subsystems
  - Linacs for NuMAX
  - RLA to reach 63 GeV
  - Low energy acceleration for colliders
  - High energy acceleration beyond 63 GeV: pulsed synchrotrons
- Some acceleration subsystems can be reused for different machines

Factors Governing Design Choices

- Sufficient longitudinal (and sometimes transverse) acceptance
- High average gradient to limit decays
- Limiting emittance growth
- Reducing impact of collective effects
- Cost control

	NuMAX	Higgs	1.5 TeV	3 TeV	≈6 TeV
E_{max} (GeV)	5	63	750	1500	≈3000
$\epsilon_{\perp}$ (μm)	2600	200–400	25	25	25
$\epsilon_{\parallel}$ (mm)	24	1.0–1.5	70	70	70

RLA to 63 GeV

- Accelerate from 5 to 63 GeV
- Use dogbone RLA
- Tolerate 10% emittance growth
- Both Higgs and high energy collider beams

N	2×10^{12}	4×10^{12}	2×10^{12}
$\epsilon_{\|}$ (mm)	1.5	1.5	70

Beam Loading

- No time to top of RF: run on stored energy
- Can tolerate ≈ 30% voltage reduction

Passes	$\Delta V/V$ (%)	
	325 MHz	650 MHz
3	5	16
5	8	26
7	11	36
9	15	47

- 9 passes fine at 325 MHz (switchyard limited)
- 3 passes fine at 650 MHz, 5 passes marginal

Droplet Design I

- Limit longitudinal emittance growth: small momentum compaction, prefer many short cells
- Avoid mismatch: arc beta similar to linac beta
- Results reasonable for Higgs longitudinal emittance
- Unacceptable for collider longitudinal emittance
  - Decays too high
  - 325 MHz better, but lots of arc
  - 650 MHz, energy spread makes it crazy

Droplet Design I

ϵ (mm)	1.5	1.5	70	70
$\omega/2\pi$ (MHz)	325	650	325	650
Linac passes	9	3	9	3
Cells/cavity	2	5	2	2
Cells/droplet	16	58	65	338
Arc length (km)	4.3	3.3	24.0	32.5
Decay (%)	8.8	5.3	17.4	20.7
σ_E (MeV)	22	50	283	647

Droplet Design II

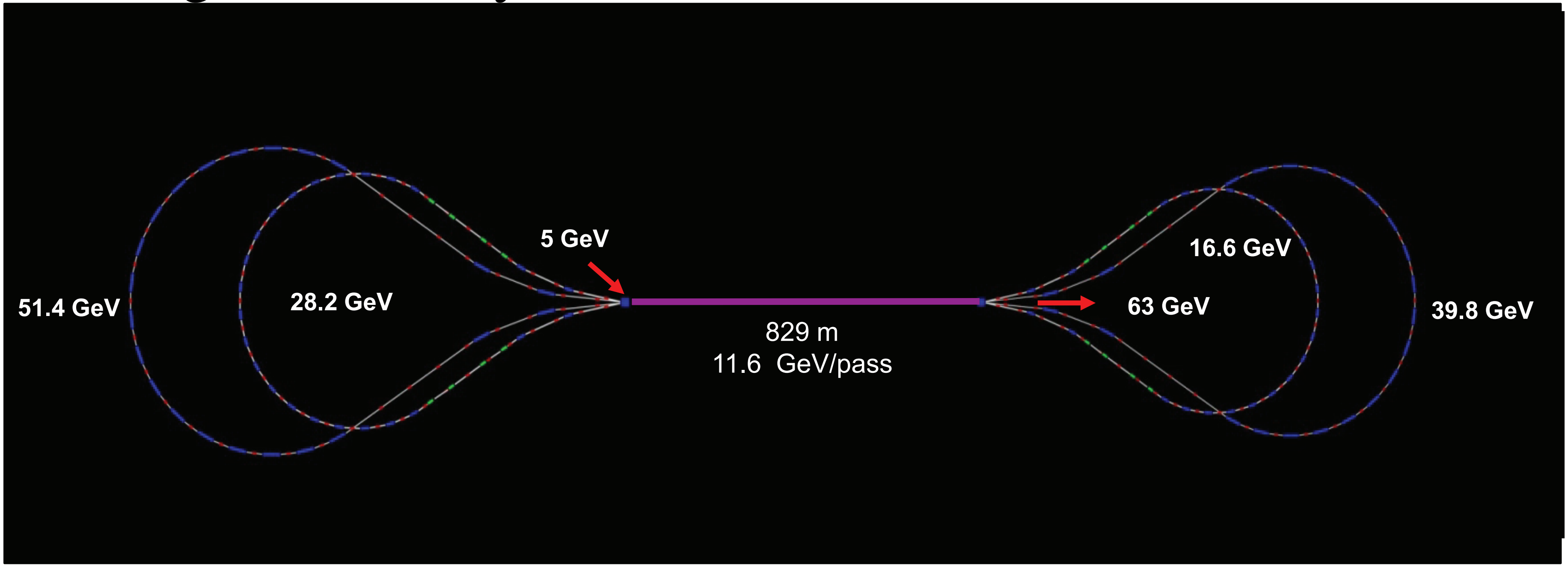
- Allow a beta mismatch between linac and arc
- Design arcs for maximum field (1.5 T warm, 6 T cold)
- Solutions look more reasonable
  - 325 MHz should use cold magnets for decays
  - 650 MHz could use warm or cold
    - Beta match easier with warm
- Linac to arc beta mismatch significant (factor of 6 in the best case)
  - Must work over large energy spread
  - Will need several arc cells to accomplish

Droplet Design II

$\omega/2\pi$ (MHz)	325	325	650	650
Linac passes	9	9	3	3
Arc dipole (T)	1.5	6	1.5	6
Cells/droplet	93	51	212	121
Arc length (km)	12.0	4.3	3.2	1.2
Decay loss (%)	12.3	9.1	6.2	6.3

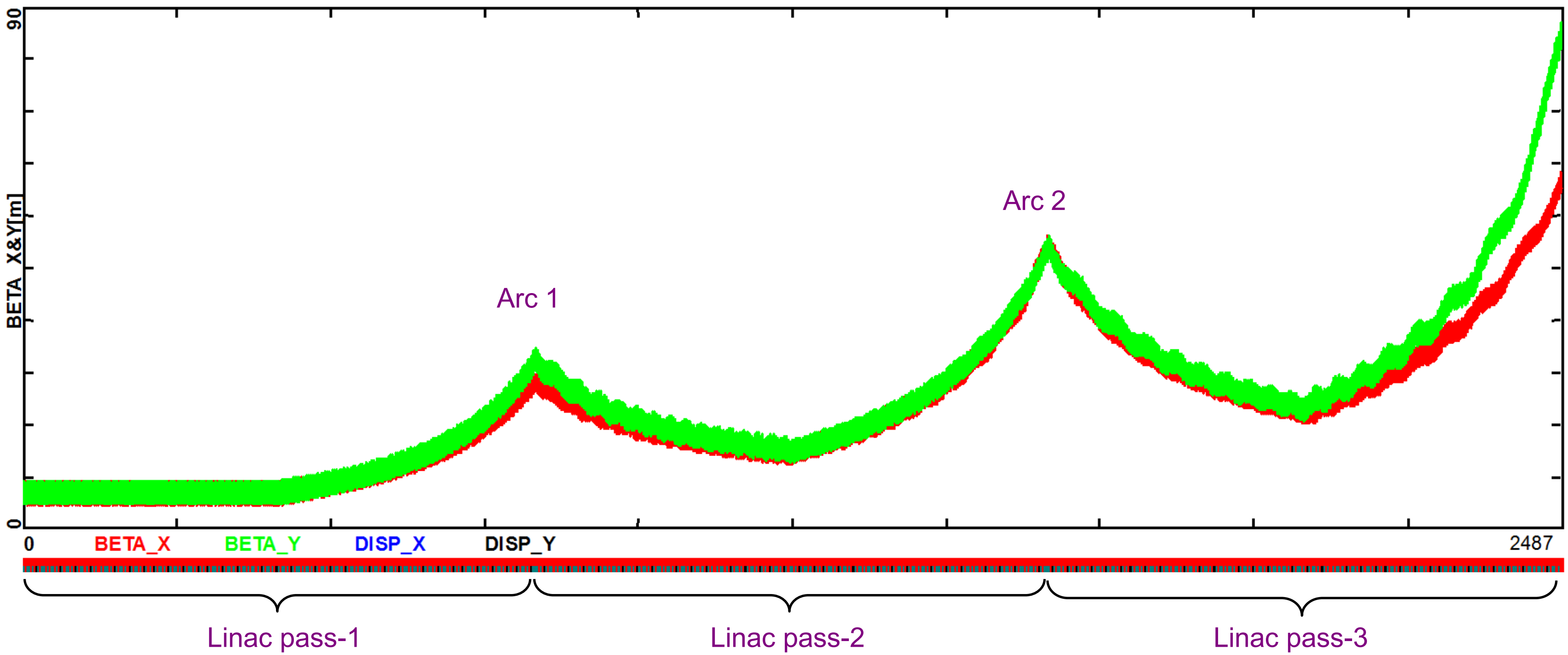
Design Work (Bogacz)

- 5 pass design
  - Shorter linac better: reduced energy spread
  - Borderline on beam loading
  - Tighter switchyard



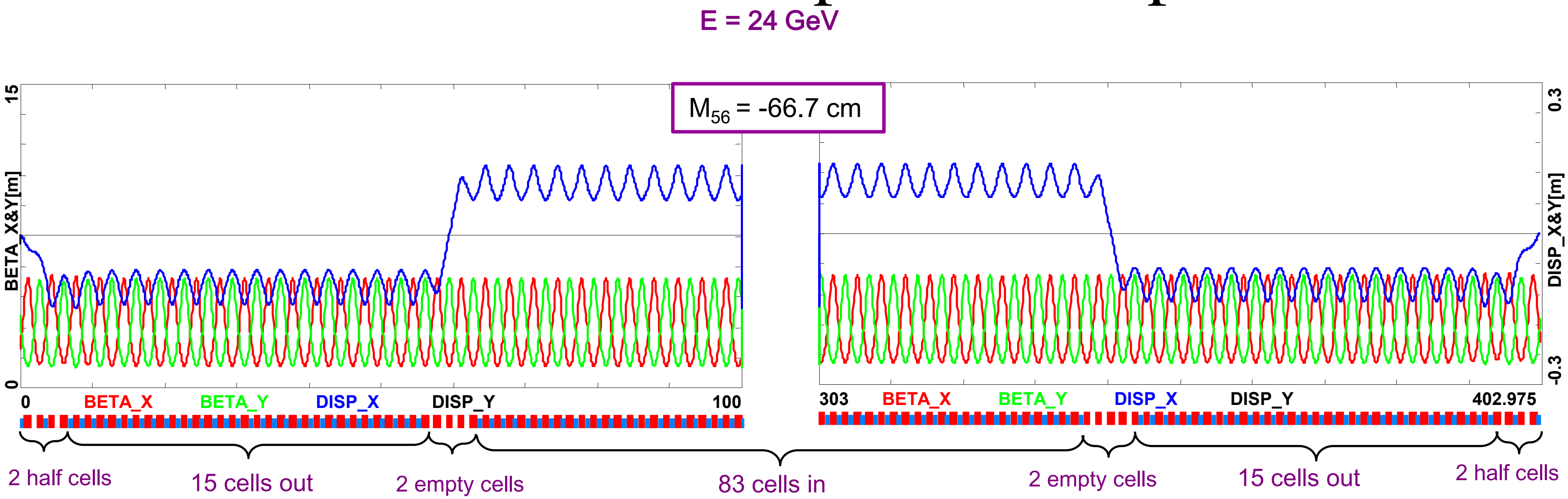
Design Work (Bogacz)

- Symmetric focusing
- Beta function at end of first pass around 30 m



Design Work (Bogacz)

- Beta functions in arc only a couple m
- Matching needs to be worked out
- Picture is for first arc of 3-pass, not 5-pass



Final Thoughts: RLAs

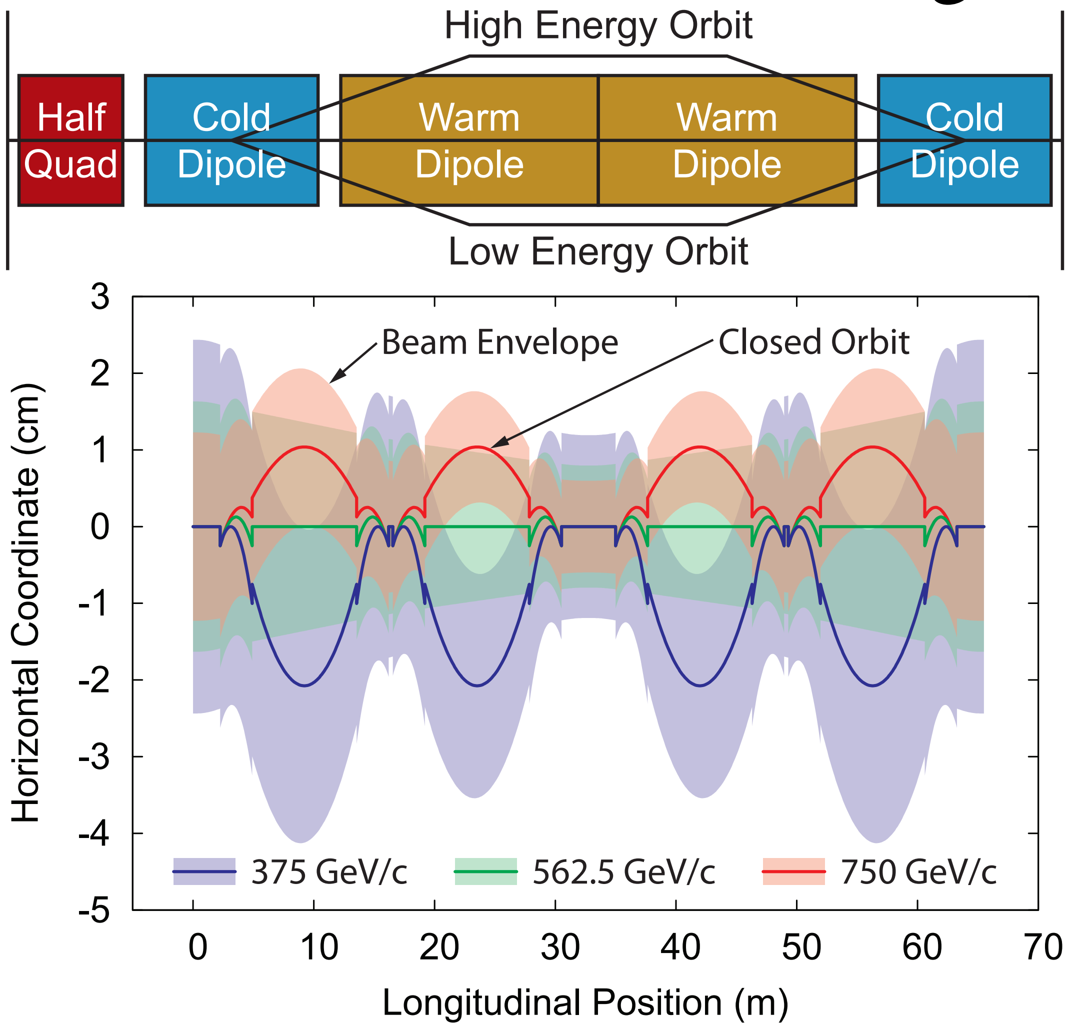
- Large energy spreads could be a problem
- Arcs get very long
  - Could reduce momentum compaction with fancier arc cell, but may take a hit in energy acceptance
- Smaller energy range may be favorable
  - Switchyards become tighter
- Racetrack will also help, but makes switchyards worse

Rapidly Pulsed Synchrotrons

- Pulse a synchrotron very rapidly as beam accelerates
- First proposed by Summers in 1996
- Permits maximal passes through RF cavities with modest apertures
- Field of pulsed magnets must be generated by iron
- Would like a higher average bend field
- Interleave superconducting fixed-field and bipolar pulsed dipoles
- Acts like a dipole with average field $(B_C L_C + B_W L_W)/(L_C + L_W)$

Rapidly Pulsed Synchrotrons

- Beam will not remain centered in magnets



Muon Collider Example

- Magnets: 10 T fixed, 1.5 T pulsed

Hybrid	p_{min} GeV/c	p_{max} GeV/c	Time ms	Turns
No	63	375	0.3	10
Yes	63	173	0.1	18
Yes	173	375	0.2	18
Yes	375	750	0.4	18
Yes	750	1500	0.8	18

Pulsed Synchroton: Lattice Design

- Interleaved arcs and linacs
  - Energy discrete, magnet fields continuous
  - Many acceleration steps: compact arcs
- Constant time of flight, tune
- Zero dispersion, closed orbit in linacs
- Correct global chromaticity
- Have sufficient longitudinal acceptance, accelerating gradient

Cell:

FL2/2	RF	DL	RF	FL1	RF	DE	B	F	B	D	B	F	B	D/2

Arc:

D/2	SD1	B		F	SF	B	SD2	D	SD2	B	SF	F		B	SD1	D/2

Pulsed Magnets

- More on these later from Witte, Piekarz
- Viable magnet designs exist with manageable losses
- Key technology questions to address next, in my opinion
  - How to power the pulsed magnets
  - How does the system respond when the magnet goes into saturation
    - Part of cycle in saturation to get linear pulse for beam (?)
    - Simulation codes tend to get unhappy
    - What happens to power losses?
    - Knowledge of material properties may be important
  - These two may be intertwined
- No funding expected for this year

Plans this FY

- Small effort, focused on primarily on pulsed synchrotrons
- Goals
  - A more detailed idea of what high energy acceleration may look like
  - Better understanding of parametric tradeoffs (number of stages, cell lengths and apertures, etc.)
- Sufficient lattice design work to work out parametric dependencies
- Some thinking about when switch to RLAs (FFAGs???) makes sense

Final Thoughts

- Acceleration is not about technical feasibility but about cost control
- Controlling large longitudinal emittance creates most of the challenges
- Pulsed synchrotrons provide a nice solution
  - Hit some limit for lower energies and shorter pulse times, but don't know where
- Even for high energy machine, need to pay attention to low energy acceleration stages so their costs don't surprise us